1.1 AN OVERVIEW OF THE 1997 ACTIVITIES OF THE SEMI-ARID LAND-SURFACE-ATMOSPHERE (SALSA) PROGRAM

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1. INTRODUCTION

The primary objective of the **S**emi-**A**rid **L**and-**S**urface-**A**tmosphere (SALSA) Program is to understand, model and predict the consequences of natural and human-induced change on the basin-wide water balance and ecological diversity of semiarid regions at event, seasonal, interannual, and decadal time scales. SALSA is a long-term program whose current research and integrated measurement efforts are focused on the San Pedro River basin which originates in northern Sonora, Mexico and flows north into southeastern Arizona. This paper provides an overview of the 1997 SALSA Program elements and data collection activities. It serves as an introduction to a number of other, more detailed, SALSA papers presented in the special session on "Integrated Observations of Semi-Arid Land-Surface-Interactions."

2. 1997 SALSA SCIENTIFIC OBJECTIVES

1997 SALSA activities are part of a longer term (3 to 10 year effort) to address the primary objective developed from initial program goals (Goodrich, 1994) and an international workshop (Wallace, 1995). The 1997 SALSA objectives, focused on priorities established at the workshop and within logistical and monetary constraints are:

1) To improve the diagnosis of surface fluxes used in atmospheric models with grid spacings of several kilometers and compare remote and *in-situ* observations with real-time model runs;

2) To initiate the development and validation of a coupled soil-vegetation-atmosphere transfer (SVAT) and vegetation growth model for semi-arid regions that will assimilate remotely sensed data with several years of observed data;

3) To conduct *in-situ* and remote measurements to: a) quantify and develop models for groundwater, surface water, and evapotranspiration interactions on a seasonal basis; b) identify plant water sources; and c) identify plant function and atmospheric controls on a semi-arid riparian system consisting of mesquite, sacaton, and cottonwood/willow vegetation communities.

4) To develop and validate aggregation schemes with data over very highly heterogeneous surfaces; and,

5) To develop a multi-scale system of landscape pattern indicators using remotely sensed data to estimate current status, trend and changes in ecological condition.

Other factors involved in the selection of the above objectives include the desire to maintain and initiate long term observations and multi-disciplinary research in the San Pedro Basin, and to assist in addressing a number of pressing socio-economic concerns in the region. Long-term monitoring and research is essential to capture a range of both seasonal and interannual climatic variations and their associated impacts on basin water resources and ecology. It is because of the long history of monitoring and multidisciplinary experimentation in the San Pedro Basin and the long-term nature of SALSA that the NASA Earth Observing System ASTER (Adv. Spaceborne Thermal Emission and Reflection Radiometer) team has selected the San Pedro as a

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regional study and validation area. Research supporting development and validation of ASTER aircraft simulator data products was also undertaken as part of 1997 SALSA objectives.

3. THE STUDY AREA

The Upper San Pedro Basin (USPB) was identified as the focal area for initial SALSA research during the 1995 workshop. The riparian system in the U.S. portion of the USPB is the first Congressionally designated National Riparian Conservation Area. The basin embodies a variety of characteristics which make it an exceptional outdoor laboratory to address a large number of scientific challenges in arid and semi-arid hydrology, meteorology, ecology, and the social and policy sciences. The area represents a transition between the Sonoran and Chihuahuan deserts with significant topographic and vegetation variation, and a highly variable climate. It is an international basin spanning the Mexico-United States Border with significantly different cross border legal and land use practices, The upper and middle portions of the basin depicted in Figure 1 have a drainage area of 7610 km^2 at the U.S. Geological Survey gaging station at Reddington, Arizona with approximately 1800 km^2 in Mexico. Elevations range from roughly 1100 to 2900 m. A color Landsat MSS image illustrating the basin's heterogeneity and cross-border land use differences is available on the SALSA home page:

http://www.tucson.ars.ag.gov/salsa/salsahome.html

The annual rainfall ranges from around 300 mm to 750 mm. Approximately 65% of this typically occurs during the July through September monsoon season from high intensity air-mass convective thunderstorms. Roughly 30% comes from less intense winter frontal systems. Potential evapotranspiration is estimated at more than ten times annual rainfall at lower elevations (Renard et al., 1993). Interannual climate variability is also high with a demonstrated linkage to the El Niño-Southern Oscillation (Woolhiser et al., 1993). Major vegetation communities include desert shrub-steppe, riparian, grasslands, oak savannah, and ponderosa pine. In portions of the basin all of these vegetation types are contained within a 20 km span. The USPB supports the second highest known number of mammal species in the world and the riparian corridor provides habitat for more than 300 bird species.

From a socio-economic perspective, great concern exists regarding the long-term viability of the San Pedro riparian system and ranching in the face of continued population growth. Groundwater sustains the riparian system in the United States and also much of the ranching industry in the Mexican portion of the San Pedro. The threat of excessive groundwater pumping to this riparian system has prompted the first application of international environmental law within the U.S. via the North American Free Trade Agreement (see Arias et al., 1998 - this issue).

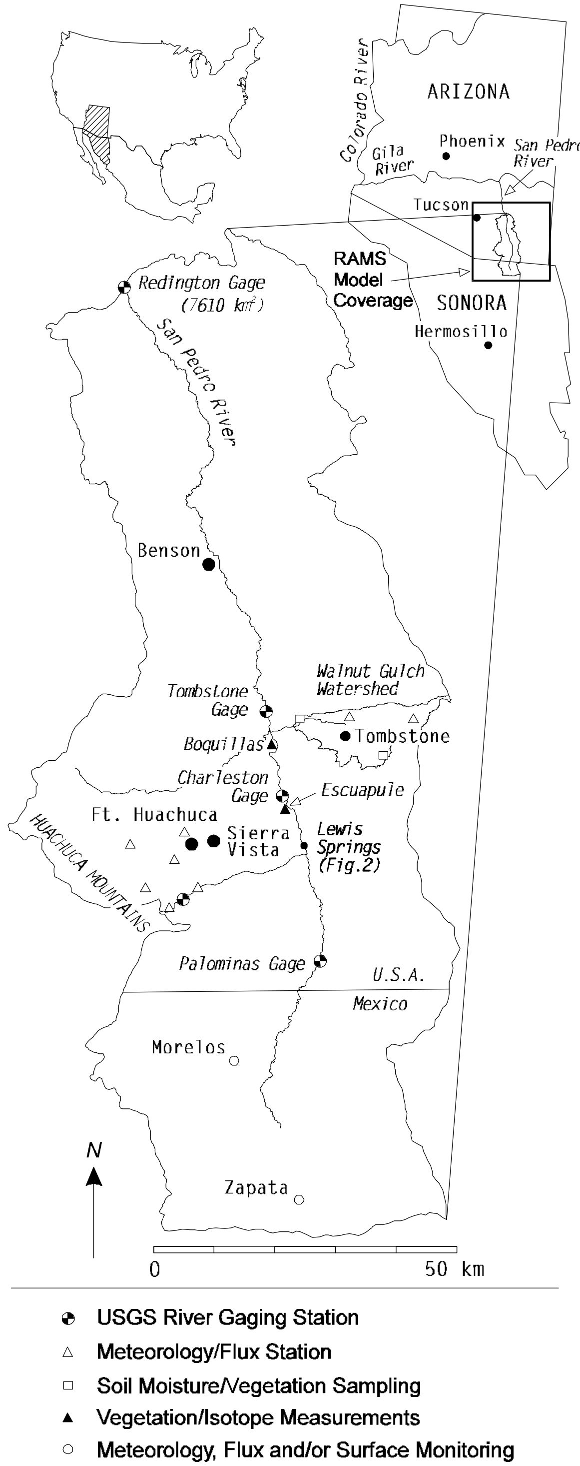


Figure 1: Upper San Pedro Basin

4. METHODS

To address the ***first objective*** the Regional Atmospheric Modeling System (RAMS) mesoscale atmospheric model was run using variable surface parameters appropriate for the region in a diagnostic mode in near real-time for all of 1997 with a 4 x 4 kilometer grid spacing over the entire San Pedro Basin (see Figure 1), Analyses and 6-hour forecasts from the operational meso-Eta model were used to generate boundary conditions and nudging tendencies for RAMS. For comparative purposes, model output was saved every 15 minutes for the grid cells closest to the experimental surface observations shown in Figure 1. In addition, all model fields were saved every 3 hours so assessments could be made of the value of integrating and assimilating both remotely sensed and *in-situ* observations (Toth et al., this issue).

Experimental surface observations were obtained from a variety of existing data collection networks. These include intensive monitoring at the 148 km^2 USDA-ARS Walnut Gulch Watershed (85 raingages, 30 runoff measurement sites, two sites with energy and CO_2 flux, meteorology, vegetation and soil moisture measurements; Renard et al., 1993), meteorological data collection by the US Army at Ft. Huachuca, and five USGS stream gaging stations.

In addition, several new intensive research and data collection sites were established during 1997 in areas having sparse desert grass cover in Mexico at Morelos and Zapata (see Figure 1). A wide variety of *in-situ* and remotely sensed data are being collected at these sites to address ***objective two***. These measurements include meteorology, energy and CO_2 fluxes, soil moisture, vegetation sampling, and surface reflectances (Chehbouni et al., this issue). Stable isotopes of water were also collected over a board transect to examine the competition for water between grass and shrubs so that the potential extension of shrub invasion into grasslands may be estimated. Extensive large scale measurements, on a scale commensurate with the resolution of the RAMS model, of sensible heat flux are also being taken at these relatively uniform sites with a scintillometer (Chehbouni et al., this issue).

In addition to the broader scale measurements noted above, an intensive set of groundwater, surface water, isotope, energy flux and plant transpiration measurements were concentrated in the Lewis Springs section of the San Pedro Riparian corridor to address ***objective three***. This stream section is a “gaining reach” where groundwater contributes water to the stream. The vegetation type and structure in the Lewis Springs area is relatively representative of vegetation throughout the 50 kilometer long San Pedro National Riparian Conservation Area. This riparian system typically consists of a narrow (20 -100m) cottonwood/willow forest gallery surrounded on either side by riparian grasses and mesquite thickets. These grow upon the ancient flood plain which varies in width from several hundred to between one and two kilometers. A schematic of a typical section of riparian corridor geometry is illustrated in the lower insert of Figure 2. A primary goal is to quantify the surface water, groundwater, and evapotranspiration fluxes into and out of the control volume as depicted in this figure.

The network of instrumentation installed at Lewis Springs to address this goal and the other aspects of ***objective three*** is illustrated in the main portion Figure 2 (Note: An illustration of the vegetation classification for this area is presented in Moran et al., this issue). Continuous measurements of water levels in the deep wells, meteorology and fluxes (Bowen Ratio) over the riparian grass and mesquite thicket (Scott et al., this issue), and stream stage at section three were made for all of 1997. Measurements were made of gravimetric soil moisture, temperature, and soil tension measurements in the near- stream bank trenches to investigate bank storage-stream conductance relationships (Whitaker et al., this issue) for the last half of 1997.

In addition to the continuous measurements, intensive synoptic in-situ and remote measurement campaigns of 32 to 56 hours were conducted in March, April, June, August, and October. This period spans the pre-green up and growing season to allow for characterization of the seasonal variations in evapotranspiration, and surface water - groundwater interactions. Measurements taken during the synoptic runs included hourly stream stage and water levels from five river sections and the piezometer network, stream discharge measurements determined by current metering, dye-dilution, and an in-stream flume for the June campaign (see summary by Maddock et al, this issue). Neutron probe measurements of soil moisture were made during synoptic runs and other periods of dynamic change. Treesap flow, water potential, stomatal conductance, and water sources using stable oxygen and hydrogen isotope ratios were determined for mesquite, cottonwood, and willow during each of the synoptic campaigns to capture variations in transpiration demand as a function of atmospheric demand and surface moisture availability. A subset of the vegetation and water source measurements was also made in a both an intermittent losing and ephemeral riparian stream reach (at Boquillas and Escapule locations, respectively - see Figure 1). This design enabled the proportion and magnitude of surface water use by the gallery trees as a function groundwater availability to be evaluated (see overview by Williams et al, this issue).

Concurrent with these *in-situ* measurements, ground-, aircraft-, and satellite-based remotely-sensed measurements were taken. Plant and soil reflectance, temperature and radar backscatter remote measurements were made during each synoptic run and at other strategic times during 1997. These data will be used to develop remote-sensing approaches for monitoring regional and riparian corridor vegetation productivity and evapotranspiration (see remote sensing summary in Moran et al, this issue).

During the August campaign a greater concentration of instrumentation, including two additional aircraft, were deployed at the Lewis Springs site from Aug. 8-19. Additional instrumentation deployed at this time included an array of eddy correlation flux instrumentation (see ET summary by Hipps et al., this issue). A scintillometer, and the Las Alamos National Laboratory Raman LIDAR system (Cooper et al., this issue). During the first portion

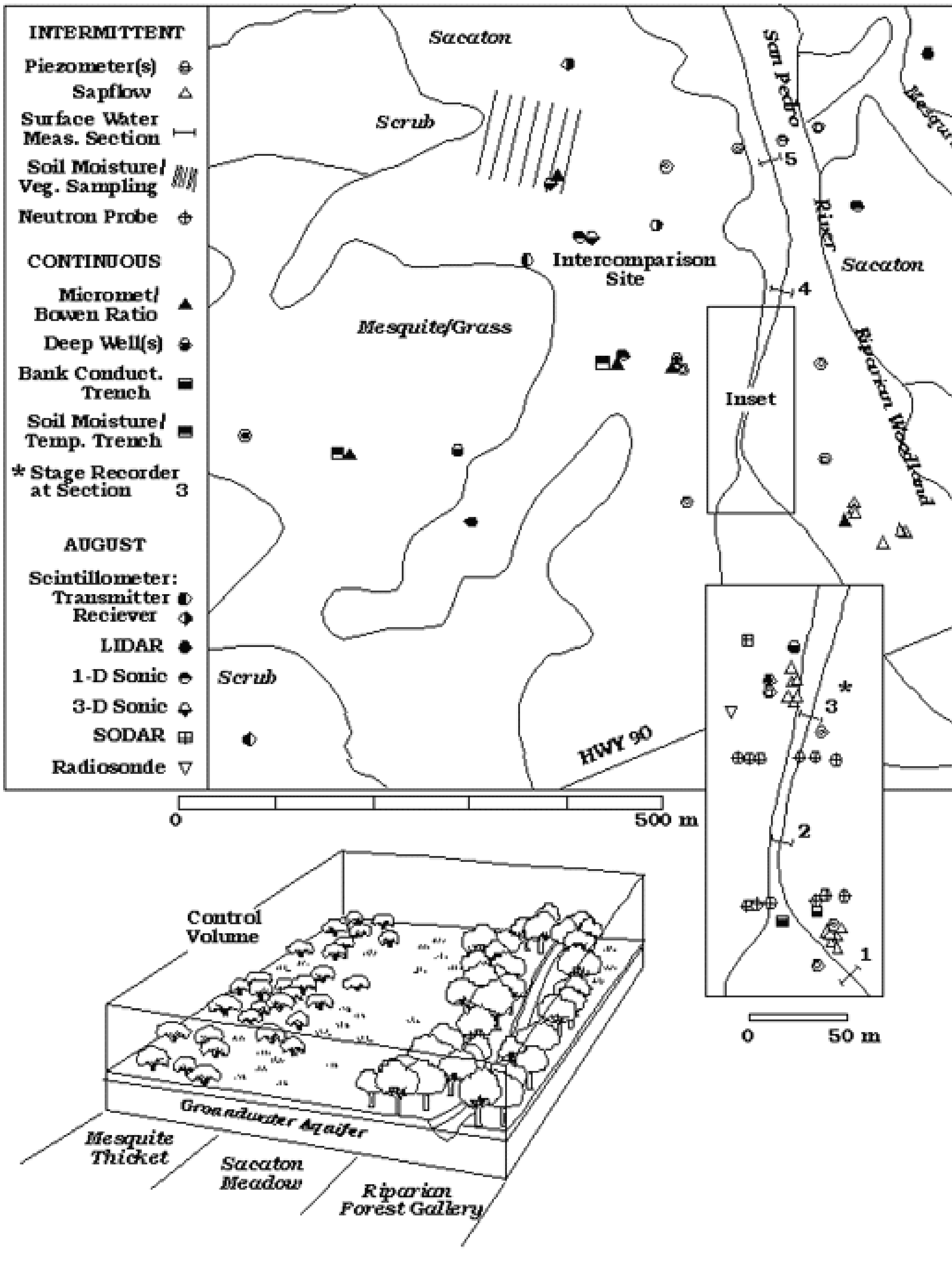


Figure 2: Lewis Springs Instrumentation and Measurement Locations

of the August campaign an intercomparison of flux instruments was conducted over a homogeneous region of the sacaton grass while the LIDAR was deployed on the east bank of the San Pedro River. After several days the LIDAR was moved to the west bank and the flux instruments were redeployed across the highly heterogeneous vegetation types under the path of the scintillometer. ***Objective four*** will be addressed with this data due to the wide variation in vegetation type, height and stress resulting from differential access to groundwater in the compact riparian area. Finally, ground-based remotely sensed observations of atmospheric moisture derived from interferometric methods (Shao et al., this volume) were also taken roughly 400 m south of the Lewis Springs site. Like the scintillometer measurements, these were taken on a scale commensurate with the resolution of the RAMS mesoscale model. The period of these measurements and those described above are summarized in the following Activity/Data Collection Chart (Table 1).

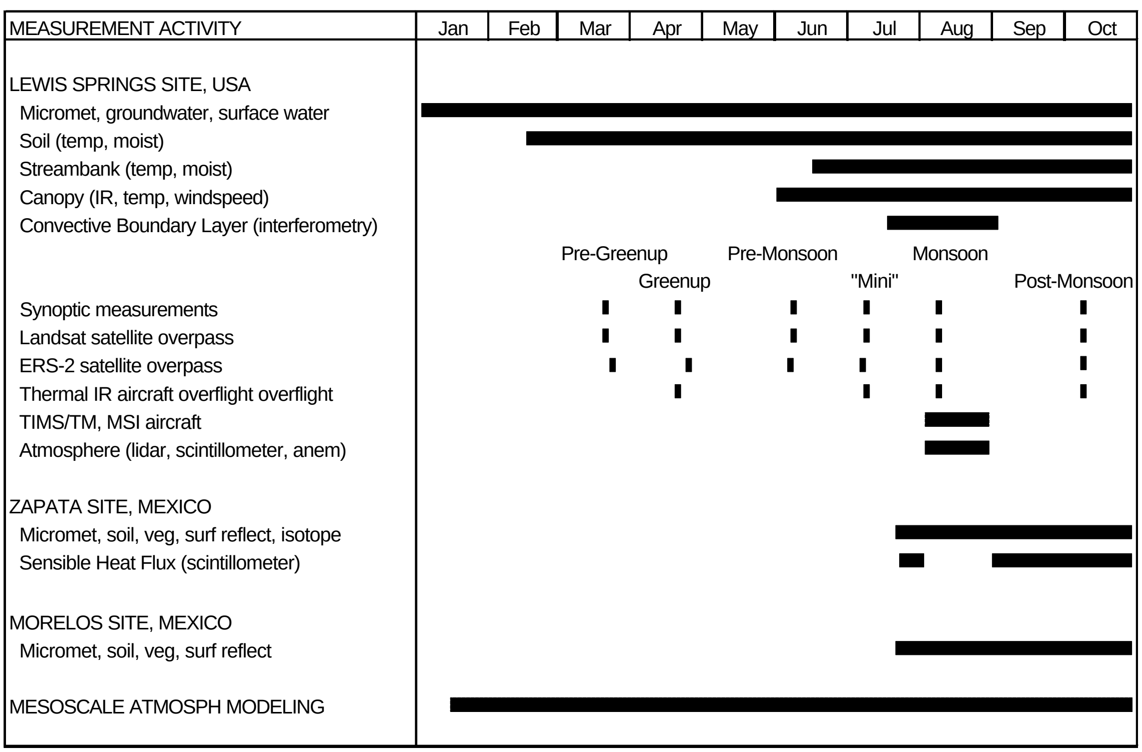
To address objective five Landsat MSS imagery was acquired over the basin from 1974, 1987, and 1991. The images have been resampled to 60 x 60 meter pixel resolution, coregistered, and georeferenced using the UTM coordinate grid. Efforts were initiated to extend an existing digital land cover map of major vegetation and land use classes for the 1974 and 1987 images in the United States into the Mexican portion of the USPB. Similar processing of the 1991 image was also initiated. Preliminary landscape pattern analysis was then conducted with several metrics to estimate changes in land cover over the period from 1974 to 1987 in the U.S. portion of the basin (Kepner et al., 1995)

5. PRELIMINARY RESULTS AND CONCLUSIONS

Preliminary findings of the mesoscale modeling effort to address objective one suggest that a detailed atmospheric model simulation (i.e. large eddy simulation) of the riparian zone will be quite a challenge. This simulation will have to incorporate the extreme heterogeneity of the Lewis Springs area with the added challenge of assimilating the observed variations in the low - level atmosphere. At grid spacings of one to four kilometers the atmospheric model may be able to diagnose the aggregate effects of increased latent heat flux in the riparian zone, but only if the regional fluxes are accurate. Toward this end several alternative surface parameterizations are being evaluated in RAMS, including the SiB2 scheme (Harlow et al., this issue). In the same vein performances of two different SVATs with two and three component models, have been tested with data collected over the Mexico and over the US (Boulet et al., this issue) Also, observed clouds will be used to correct the model's net radiation (Yucel et al., this issue).

A preliminary result of the research addressing

Table 1. Schedule of SALSA activities, 1997.



objective two is the development of a vegetation growth model for desert grasslands (Nouvellon et al., this issue). Furthermore, analysis of a detailed data set collected in 1996 indicates that biomass predicted by the model is very well correlated with measured surface reflectances (Bégué et al., this issue). In addition, satellite-based measurements of radar backscatter were related directly to surface soil moisture conditions in grassland and shrubland sites associated with the USPB (Moran et al(b), this volume).

Major progress was made in addressing ***objective three*** through a series of successful experimental campaigns. An initial completed product is a 5 m resolution map of vegetation classes produced using data from the aircraft-based JPL TM-simulator aboard the DOE/NASA Cessna Citation aircraft. This map will serve as a foundation for the work within the riparian zone.

Work is proceeding to combine this information with other remote sensing data and ground-based flux measurements to estimate the evaporative water loss over the USPB riparian corridor. These evapotranspiration losses had a significant impact on both stream discharge and near stream groundwater levels (MacNish et al., this issue). Prior to green-up and inputs from storm flows, discharge at both Lewis Springs and the Charleston gage were very stable. After green-up of the cottonwoods and willows, stream discharge decreased and a distinct diurnal pattern in stream discharge was apparent.

Initial results also indicate that diurnal and seasonal variations in stomatal conductance and transpiration in cottonwood and willow were strongly influenced by radiation inputs and vapor pressure deficit (VPD). Transpiration fluxes at Lewis Springs were about 12% lower during the June observation period compared to that in August, which was proportional to differences in VPD. Water potential gradients between the rhizosphere and leaf during maximum transpiration, however, were higher in June than in August, suggesting that hydraulic conductivity of trees may have increased over the growing season. Stable isotope analysis revealed that cottonwood along the river at the perennial Lewis Springs site used only groundwater and did not take up surface water even following a large rain and flood event in August. Mesquite at this site likewise used mostly groundwater over the growing season, but shifted to predominantly surface water usage at an intermittent section of the stream (Boquillas site, Figure 1) following the monsoon rains (Williams et al., this issue). Further from the river (100-300 m) at Lewis, initial findings indicate that mesquite and sacaton did not use groundwater (Scott et al., this issue). These data, taken together, illustrate the complex nature of plant controls on ecosystem water fluxes within desert riparian ecosystems.

Initial results related to ***objective four*** indicate that sensible heat flux estimates from the 3-D sonics and scintillometer compare well over uniform terrain in both the U.S. and Mexico. Good comparisons were also obtained between the scintillometer and a weighted average sensible heat fluxes derived from the 3-D sonics over the mesquite-grass transect at Lewis Springs. In this case, this implies that a simple aggregation rule can provide good results (Chehbouni et al., this issue).

Results related to ***objective five*** indicated a 35% decrease in the grasslands, an 11% increase in desert shrubs, and a 50% increase in woodlands over a large area of the USPB in the 13- year span between 1974 and 1987. The grasslands also became much more fragmented with the number of grassland patches increasing 61% while the average patch size of the grasslands decreased 60%. These changes will have different implications for habitat suitability for various species due to differences in life history and scale requirements (i.e. patch size). However, for large grazing mammals such as the Mexican pronghorn the changes appear to be quite severe with an estimated 70% reduction in suitable habitat (Kepner, et al., 1995).

In conclusion it should also be noted that the SALSA Program activities have broken new ground in the approach to large-scale multidisciplinary science where limited resources were available. Careful planning resulted in the identification of critical scientific challenges, of such complexity, as to require the joining of disciplinary forces to address them. Careful attention to fostering interdisciplinary communication built the foundation for trustful collaborations. This enabled unselfish sharing of numerous small grants and in-kind resources to accomplish a goal which is much greater than the sum of the disciplinary parts. An additional driving force behind the SALSA Program's success is the knowledge that the results of this research will directly aid land managers and decision makers in the near term.

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